THE UNIVERSITY OF ALBERTA

COMPUTERIZED MAP: CITY OF EDMONTON

BY

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ABSTRACT

The purpose of this project was to construct a data base of the city of Edmonton. The data base contains the (X,Y) co-ordinates of each thoroughfare (bending point, end point, and intersection) plus some pseudo-intersections (river, and creeks). The begin and end numbers of each address range has been included with the co-ordinates, and a computer program was written to determine the (X,Y) co-ordinates corresponding to a given address. Further, computer programs were constructed (using point-in-polygon methods) to determine in which partition of a particular partitioning of the city a given address is located. The data base was verified by comparing a plotted map of 1"/1000' to a city base map of the same scale. In addition the city was partioned into census districts and the residential addresses of the academic staff members at the University of Alberta were tabulated by census district.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

> Good planning - whether for transportation systems or for entire cities - requires accurate, up-to-date information organized for easy access and evaluation. City data banks are therefore being developed for the accumulation of departmental files in a form that allows all agencies to draw on them for planning. The basis of the files must necessarily be geography, since the location of people, businesses, services and facilities is the primary interest.
> By means of display terminals or digital plotters, maps can be displayed showing densities of housing, crime, traffic, telephones - in short, anything measurable - using the most recent available data. The location of a new school could clearly be better chosen if the future distribution of school children in the district could be projected and translated into a series of maps....[1]

The above quotation sketches a line of development which is of great importance, but it may give the reader the impression that these maps, can be brought into existence almost effortlessly. This is true but, only after someone has collected masses of data and put it in a form suitable for computer processing. A considerable number of projects are at various stages of development in Canada and other

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[1] Martin, James and Norman, Adriaan R. D., <u>The Computerized Society</u>, Prentice-Hall, Englewood Cliffs, N.J., 1970, p. 261

parts of the world. For example an information system GIST[2] was initiated in New York in 1968 to describe land, streets and buildings in the city, while another system COGO[3] is being developed at the Urban Systems Laboratory at the Massachussets Institute of Technology.

Agencies which have as their primary task the assembling of data on land, water and human resources are ARDA[4] in Canada and FRIS[5] in Sweden. The United States Bureau of the Census, another agency has been a leading innovator in the gathering and automatic processing of gigantic quantities of data. In fact it had a considerable influence in the early development of automatic data-processing equipment.[6]

Most of the publications dealing with information systems either describe a system in broad generalities or

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[2] Amsterdam, R., "Implementation of the GIST Geographic Base File", Proc., Assoc. Computing Machinery Conf., Chicago, 1971, pp. 315-324

[3] Schumacker, Betsy, "Urban COGO - A Geographic Based Land Information System", Proc., Fall Joint Computing Conf., Las Vegas, 1971, pp. 619-630

[4] Tomlinson, R. F., An Introduction to the Geo-Information System of Canada Land Inventory. ARDA, Can. Dept. of Forestry and Rural Develop., Ottawa, 1967, 23 pp.

[5] Alfredsson, Bjorn, Salomonsson, Owe and Selander Krister, A Spatial Information Study. Introduction, Central Board for Real Estate Data, Stockholm, Sweden, May 1970, 9 pp.

[6] Goldstine, Herman H., The Computer from Pascal to Von Neumann, Princeton Univ. Press, Princeton, N.J., 1942, pp. 65-71

else concentrate on the details of cnly one aspect of that system. This thesis describes the methods used in constructing a particular system, and some methods for using it. The system to be constructed and described is a computerized map of the city of Edmonton, containing information so that the physical location corresponding to an address can be determined.

1.2 MAPPING

A map (in the geographical sense) can be defined as a mapping (in the mathematical sense) from one set to another. Consider a set M of ordered pairs A X W where A = {Ai} is a set of ordered n-tuples, and W = {Wi} is a set of ordered m-tuples (where m and n may or may not be equal). If in the set M no two elements have the same first component A, then M is called a function of A onto W, where the domain of M is A and the range is W.

In Geography a few typical domains would be:

1. The ordered pair (θ,∅) giving the longitude and latitude of a point on the earth's surface;

2. The ordered pair (X,Y) where X is the distance of a point on the earth's surface east (positive) or west

(negative) with respect to an arbitarily chosen origin, and Y is similarly the distance of that point (X,Y) north or south of the same origin;

3. Address pairs - e.g., (02904,130) representing 02904-130 Street or possibly address triples, as (02904,130,S) for the same address where S could also be A (Avenue).

A typical mapping might be for instance from either of the domains $(\theta,\emptyset)$ or (X,Y) onto one of the ranges:

1. H (altitude above sea level) or R (radius from the center of the earth);

2. {0,1} where 0 = land and 1 = water.

A geographer's map can be seen as a function whose range is an l-tuple of {Wi} such as mentioned above. Consider

$$f = \underline{A} \times \underline{W} \text{ where } \underline{A} = \{(\theta i,\emptyset i)\} \text{ and}$$

$$\underline{W} = \{(Xi,Yi),\ Hi,\ Ri,\ldots\};\ \text{i.e.,}$$

$$f = \{((\theta i,\emptyset i),(Xi,Yi),\ Hi,\ Ri,\ldots)\}.$$

The function becomes an (l+1)-tuple if the parentheses about the l-tuple are deleted. It is now possible to permute the elements of the (l+1)-tuple and recombine the last elements to form an l-tuple, thereby forming a new function provided

that the uniqueness axiom is satisfied.

Thus a "data bank" of (l+1)-tuples might be used to construct a number of functions. These functions, defined by stored data, might be used to construct "models" of some geographical region or unit. In a static sense, a map can be drawn on paper, while in a dynamic sense simulations can be performed.

1.3 PROJECT AIMS

The aims of this project are:

1. To construct a data base for the city of Edmonton which contains (X,Y) co-ordinates and address co-ordinates. Since an infinite number of (X,Y) co-ordinates and address co-ordinates would be impossible to handle, the (X,Y) and address co-ordinates of the end points, intersections, and bending points of all thoroughfares in the city were included. These points are arranged sequentially from end to end of each thoroughfare. This gives sufficient information to calculate reasonable approximations to any points not actually included;

2. To write programs to use this data base to plot a map of the entire city of Edmonton, or of well defined sections of the city;

3. To write a program which, given a partitioning of the city into mutually exclusive polygonal areas[7] (e.g., wards, census districts) determines the area in which each address in a given list of addresses is located;

4. To demonstrate a method of using the data base, by determining the residential distributions of a test population;

5. To write programs to facilitate the maintenance and updating of the data base.

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[7] Nordbeck, S. and Rystedt, B., Point in Polygon Methods, Lund Series C, No.7, C.W.K. Gleerup, Lund, Sweden, 1967, pp. 7-31

CHAPTER 2

THE DATA BASE

2.1 INTRODUCTION

A data base is a collection of one or more "files". For this study, the major purpose of the data base is, together with some computer programs, to define a mapping from address co-ordinates to (X,Y) co-ordinates. The data base could also include other information associated with address co-ordinates, such as altitude, street width, paving material and one-way street indications. This chapter is concerned with the mapping to (X,Y) co-ordinates; the other information may be included later.

There are several sets of points that could be selected to represent the city. Some of these sets of points are:

1. A separate point for each plat. This point could be the geometrical center of the plat or the center of the plat along the block face. Any such scheme would involve in the neighborhood of 200,000 points (population of Edmonton is approximately 500,000). Several

disadvantages of such a scheme are: (a) the sheer size of the data base (which at 50 characters for a point might exceed 10,000,000 characters) would make it difficult to access information economically; (b) the difficulty involved in collecting and coding that amount of raw data seems insurmountable; (c) the information concerning the roadways would be indirectly obtainable at best.

2. A point at each corner of each city block. This scheme, as apposed to the one above, might require "only" about 100,000 points, and the data could be relatively easily obtained from a base map. Furthermore the roadways are more easily discernible.

3. A point in the middle of each road intersection (and a few others; e.g., bending points, and end points). This scheme cuts the number of points required by a factor of about four. In addition, the points are relatively easily obtained from a base map and the roadways are clear.

In general it is desirable that a data base be as small as possible (while still containing the necessary information) in order to minimize the effort involved in creating and updating it, and to minimize the amount of computer time involved in using it.

The first system mentioned above provides the position corresponding to a given address directly, but is impracticably large. The second and third schemes require interpolation and even then give only approximate results; nevertheless, they are practicable. Since these systems provide about equal information and the latter of them requires a much smaller data base, it was chosen for this study.

2.2 DEFINITIONS

For the purposes of this study it is necessary to give precise definitions for "address" and "position". A discussion of some data processing terms is also included.

2.2.1 Address

An "address" is defined as an ordered pair:

address = (ROADNAME, NUMBER)

where ROADNAME is the name of a thoroughfare (street,

avenue, road), and the NUMBER is house number on the thoroughfare. For example the address "10116 Malmo Road" is:

address = (MALMOROAD, 10116).

The NUMBER (e.g., 10116) uniquely indicates a position along the thoroughfare. The ROADNAME of a numbered street is the letter "S" followed by a three digit street number; e.g., S004, S029, and S165. In addition, a road such as 108A street would have the ROADNAME S108A and 114B street would be S114B. In a similar fashion the ROADNAME of a numbered avenue begins with "A"; e.g., A037, A097B and A136A. The ROADNAME of a named road is just that name; e.g., FORTROAD, FULTONDRIVE and MALMOROAD. In addition a few fictitious ROADNAMES have been invented; e.g., BOUNDARY (city boundary), RRY (railway), RIVERN (north bank of the North Saskatchewan River), RIVERS (south bank of the North Saskatchewan River), HWYnn (highway with "nn" representing the highway number), and the names of some bridges, under- and over-passes, and creeks. Furthermore, since A112 runs parallel to itself (near Borden Park), the portion of the avenue lined with buildings has been denoted as A112, while the highway portion has been denoted as A112N.

In cases where a portion of a road has two names (e.g., 82nd avenue and Whyte Avenue, 101 avenue and Jasper Avenue), both names have been included.

There are a number of housing projects and shopping centers in which the units do not have normal addresses as described above. Here the name of the project has been used as the ROADNAME, and the unit number within the project has been used as the NUMBER. For example unit 316 in Southridge has the address:

(SOUTHRIDGE, 00316).

2.2.2 Position

A "position" is defined as an ordered pair:

position = (X,Y)

where "X" is the number of feet east or west of an arbitarily chosen "origin", and "Y" is the distance north or south of that origin. The intersection of 101 street and Jasper Avenue has arbitrarily been selected as the origin. (This intersection is felt by most Edmontonians to be "the center of town", and in an areal sense is located "more or less" in the center of the city.)

2.2.3 Some Data-Processing Terms

A "file" is a collection of "records", each record consisting of a number of "fields", and each field consisting of a number of "characters". Each character is

either a blank, one of the 26 letters of the alphabet, one of the digits (0 to 9) or one of the "special" characters; e.g., asterisk, dot, or ampersand.

The "width" of a field is the number of characters comprising it, and the "size" of a record is the sum of the widths of its fields. The "size" of a file may be either the number of records comprising it or the sum of their sizes.

Usually the nth field of each record is of the same width as the nth field of any other record in the file.

2.3 FORMAT OF THE DATA BASE (FOR A MAP)

It is proposed that the data base be composed of two files, the Address/Position File and the Index File. The second is not strictly necessary but it will improve access time to records in the first file.

2.3.1 Address/Position File (File 1)

The first file consists of records of two types, Master Records and Detail Records, as shown in fig. 1.

FIGURE 1

RECORD FORMATS FOR FILE 1 AND FILE 2

File 1 - Master Record

SERIAL NUMBER		ROADNAME (4 TO 29 CHARACTERS)

The second field is L, R, A, B, or blank.

File 1 - Detail Record

SERIAL NUMBER		X COORD	Y COORD	BEGIN ADDR.	END ADDR.	ROADNAME (0 TO 29 CHARACTERS)

The second field is &, #, or blank.

File 2

D A I D S D K R	ROADNAME (4 TO 29 CHARACTERS)

2.3.1.1 Format of Master Records

The first record type is used to introduce a sequence of records of the second type, called Detail Records. Each Master Record consists of three fields. The first field is seven characters long and contains a serial number for the record (the last three characters are always 000 to indicate that this is a Master Record). The second field is one character long and contains either "A", "B", L", "R", or "ƀ" (blank). The "R" and "L" signify that as the main thoroughfare is travelled in the direction indicated by the immediately following sequence of Detail Records, the odd street addresses are to the right "R" or to the left "L". The "A" and "B" signify that all street addresses are to the right "A", or to the left "B". This field is left blank for those thoroughfares and fictitious thoroughfares for which street addresses are inappropriate; e.g., Emily Murphy Park Road, river banks, and creeks. The third field is of some length between four and twenty-nine characters, and contains the ROADNAME of the main thoroughfare (or the name of a housing project or shopping center).

2.3.1.2 Format of Detail Records

Each Master Record specifies some main thoroughfare,

and is followed by a sequence of Detail Records, which specify points along that thoroughfare: these points are in order from one end of the thoroughfare to the other, and the Detail Records are in the same order.

The first field of each Detail Record is a seven-character serial number whose first four characters are the same as the first four characters of the preceding Master Record, and whose final three characters are 005 for the first Detail Record, 010 for the second one, and so on.

The second field is one character long and is either "ƀ" , "#", or "&". The significance of this field will be discussed below.

The third and fourth fields are each six characters long, and give the X and Y co-ordinates, respectively, of the point. Negative values of X indicate that the point is to the west of the origin, and negative Y values indicate to the south of the origin.

The fifth field is six characters long and, if not blank indicates the first address in the interval from the point defined by the current record, and that defined by the next record with a nonblank sixth field. The sixth field, if not blank is also six characters long. It indicates the last address in the interval from the point defined by the last previous record with a non-blank fifth field to that defined by the current record.

The seventh field is 0 to 29 characters long, and if it is not empty it specifies the name of an intersecting thoroughfare.

Detail Records are given for four types of situations:

1. An intersection with the main thoroughfare, in which case, the second field is blank or "&", and the seventh field specifies the name of the intersecting thoroughfare; or,

2. A pseudo-intersection (It sometimes occurs that a house number passes an exact multiple of 100, somewhere other than at an intersection; such a point is called a pseudo-intersection.) A pseudo-intersection is represented by a record whose second field is "#", and whose seventh field is empty; or,

3. An end point (including intermediate end points) of the main thoroughfare, in which case, the second field is "&". If the end point coincides with an intersection (e.g., a T junction), then the seventh field specifies the name of the intersecting thoroughfare;

otherwise, the seventh field is empty; or,

4. A bending point (which does not coincide with an intersection) of the main thoroughfare, in which case, the second field if "#" and the seventh field is empty. The bending points have been introduced to mirror the fact that many thoroughfares (especially in the outlying districts) curve unpredictably between intersections.

Note that no distinction has been made between the coding of the pseudo-intersections and the bending points; in fact, many bending points are pseudo-intersections.

Should it occur that a main thoroughfare is intersected at a given point by more than one thoroughfare then a separate Detail Record for each of the intersecting thoroughfares is included in the file. The first six fields of each of these records are identical. For example, the file might contain records shown in fig. 3 to correspond to the situation shown in fig. 2.

Housing projects and shopping centers have been treated as single points. One Detail Record is included with the lowest unit number in its fifth field ("begin address"), and another Detail Record has the highest unit number ("end

address") in its sixth field. The (X,Y) co-ordinates are the same on both records.

Thus the Address/Position File, also known as File 1, (consisting of Master Records and Detail Records) provides the information necessary for calculating the (approximate) position of any given address.

2.3.2 Index File (File 2)

The Address/Position File is, by itself, logically sufficient for the purposes of this study, but to find a particular address it is necessary to scan through File 1 from the beginning to the point where the desired address is found. If the file is on magnetic tape, this is the only procedure possible; however, if a Direct Access Storage Device (e.g., drum or disk) is available, it is possible to shorten this searching process drastically by making use of the Index File.

FIGURE 2

ILLUSTRATION OF SOME TYPICAL THOROUGHFARES

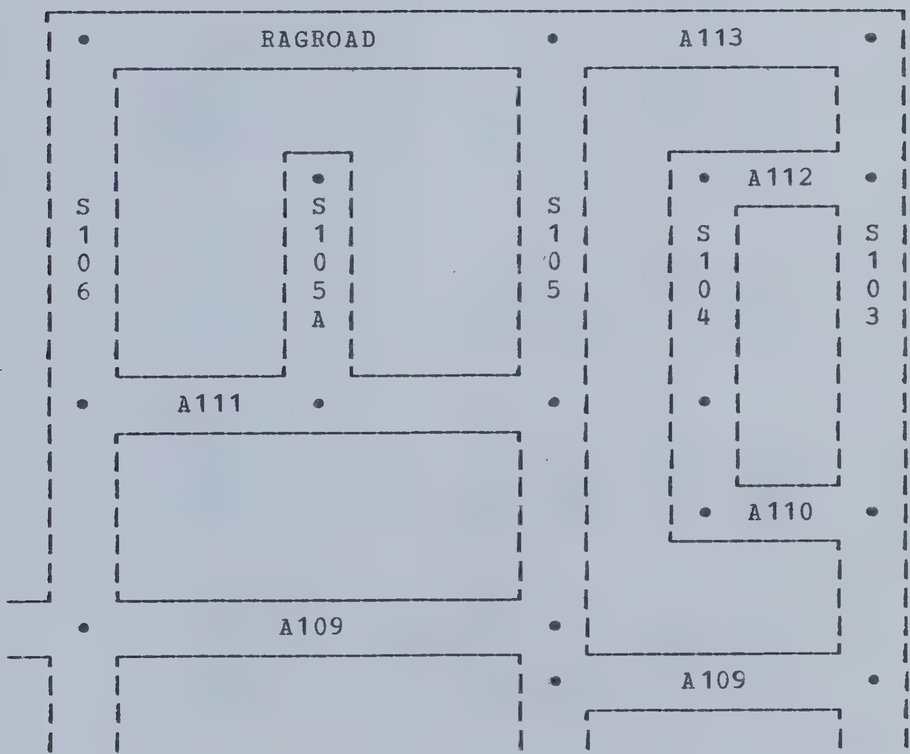

FIGURE 3

MASTER AND DETAIL RECORDS FOR SOME

TYPICAL THOROUGHFARES

```
0001000 R A113

0001005 &  -950  3818        10539 S106
0001010    -382  3818 10502        S105
0001015 &  -182  3818              S103


0002000 R A112

0002005 &  -275  3535        10313 S104
0002010 &  -182  3535 10301        S103


0003000 R A111

0003005 &  -950  3166        10538 S106
0003010    -771  3166 10519  10516 S105A
0003015 &  -382  3166 10501        S105


0004000 R A110

0004005 &  -275  2875        10307 S104
0004010 &  -182  2875 10303        S103


0005000 R A109

0005025    -950  2588        10562 S106
0005030 &  -382  2588 10505        S105
0005035 &  -382  2405              S105
0005040 &  -182  2405              S103
```

FIGURE 3
(continued)

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0025000 R S106

0025005 &  -950  3818                    A113
0025005 &  -950  3818                    RAGROAD
0025010    -950  3166                    A111
0025015    -950  2588                    A109

0026000 R S105A

0026005 &  -771  3535             11108
0026010 &  -771  3166  11102             A111

0027005 R S105

0027005 &  -382  3818                    A113
0027005 &  -382  3818                    RAGROAD
0027010    -382  3166                    A111
0027015    -382  2588                    A109
0027020    -382  2405                    A109

0028000 R S104

0028005 &  -275  3535             11136 A112
0028010 #  -275  3166  11103 11012
0028015 &  -275  2875  11002             A110

0029000 R S103

0029005 &  -182  3818             11208 A113
0029005 &  -182  3818             11208 RAGROAD
0029010    -182  3535  11202             A110
0029015    -182  2875             10912 A109

00105000 R RAGROAD

00105005 &  -950  3818             10539 S106
00105010    -382  3818  10502             S105
00105015 &  -182  3818                   S103
```

2.3.2.1 Format of Index File

The Index File contains one and only one record for each ROADNAME. Each record contains two fields, of which, the first is four characters in length and specifies the address in disk storage of the first record pertaining to the ROADNAME. The second field is twenty-nine characters in length and contains the ROADNAME. (See fig. 1.)

Assuming the Address/Position File has been stored on disk, it is then possible, rather than searching the entire Address/Position File, instead to scan the much shorter Index File for the desired ROADNAME and then resume the scan in the Address/Position File for only those records pertaining to the given ROADNAME.

Since the Index File will probably contain fewer than 500 records, each of thirty-three characters, or 16,500 in all, it may be practical to maintain the Index File in the computer's main memory.

2.4 CREATING THE DATA BASE

The data base was created by manually entering a list of points of intersection (and other points) from a base map into a file. Then the address ranges were obtained, and

associated with the appropriate records (points). Then the (X,Y) co-ordinates of each point were obtained using a digitizer and were associated with their corresponding records. Finally, the computer was used to plot a map from the file, and the map was checked against the original. The following sections describe these steps in more detail.

2.4.1 Base Map

The conventional map from which most details of the computer map were derived is a 1"/1000' base map obtained from the Planning Department, City Hall, Edmonton. Though the base map was assumed to be reasonably accurate, it was, nevertheless, found necessary to consult road maps, and more detailed maps with scales of 1"/500' and 1"/100', and to make a number of observations in the field.

The scale 1"/1000' was chosen because:

1. The map at this scale is not too unwieldy; and,

2. The digitizing equipment available has a resolution of .01 inch, which corresponds to 10 feet. In view of the fact that a typical plat is at least thirty-five feet wide, this degree of resolution is sufficient to distinguish

between adjacent plats.

When the identity of each thoroughfare segment had been established, then each avenue on the map was scanned, by hand, sequentially, from west to east. Each time a pseudo-intersection, end point or intersection was encountered a record (in the case of synonyms, several records) was created as part of the Address/Position file. The streets were treated similarly, scanning from north to south, and all other thoroughfares were treated analogously.

2.4.2 Address Ranges

An address range is defined as the smallest and largest numbers corresponding to unique points along a thoroughfare. (e.g., intersections, endpoints and pseudo-intersections). For instance, suppose that between the intersections of S101 and S102 with A100, the "buildings" on A100 have address numbers between 10103 and 10139, then the address range begins with 10103 and ends with 10139.

For any given address range the begin-address number is contained within the fifth field of the Detail Record corresponding to it, and the end-address number in the sixth field of the (following) Detail Record corresponding to it. (See fig. 2 and fig. 3.)

In Edmonton, address ranges tend to have the property

that the first three digits of the begin and end address numbers are identical (e.g., 10139, 10158, and 07516, 07521). This fact could be used to decrease the size of the records; however, the address ranges in many cities do not have this property, (This is true, especially, of many European cities.) and, hence, it has not been assumed in the present system.

For the city of Edmonton, address ranges have been taken from "Henderson's Edmonton Alberta City Directory 1971".[1] In a number of instances, Henderson's data was found to be inconsistent with the base maps, and field checks were therefore made. These checks often resulted in amendments being made to both the base map and the Address/Position file.

2.4.3 Digitizing

The (X,Y) co-ordinates corresponding to each record in the Address/Position file were obtained using the digitizer ("graphitizer") at University of Alberta Computing Services.

A digitizer is a machine consisting of a table (bed) and a moveable cursor. If the operator positions the cursor

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[1] Hendersons Directories, Henderson's Edmonton Alberta City Directory 1971, Hendersons Directories, ltd, Winnipeg, 1971, pp. 1-289

on some point on the table and pushes the appropriate button, then the (X,Y) co-ordinates of the point relative to the axis system of the digitizer are recorded on magnetic tape.

The digitizer was used by securing the base map to the table and moving the cursor to the point corresponding to each Detail Record in the Address/Position file, and recording the position of that point with respect to the digitizer's axis system.

It is necessary to transform the co-ordinates of a point given in the digitizer's axis system into the co-ordinates of that point in the map's axis system. Letting (X,Y) be the co-ordinates of an arbitrary point in the map's system, and (X',Y') the co-ordinates in the digitizer's system, then

$$X = AX' + BY'$$
$$Y = CX' + DY'$$

where "A", "B", "C" and "D" are constants.

In order to determine the values of these constants ("A", "B", "C", "D"), two points "P1" and "P2" might be chosen. Let P1 = (X1,Y1) in the map's system, and P1' = (X1',Y1') in the digitizer's system, and similarly for P2. This gives rise to the following set of equations:

$$X1 = AX1' + BY1'$$

$$X2 = AX2' + BY2'$$

$$Y1 = CX1' + DY1'$$

$$Y2 = CX2' + DY2'$$

whose solution is

$$A = \frac{X1 - BY1'}{X1'}$$

$$B = \frac{X1'X2 - X1}{X1'Y2' - X2'Y1'}$$

$$C = \frac{Y1 - DY1'}{X1'}$$

$$D = \frac{Y1'Y2 - Y1}{Y1'X2' - Y2'X1'}$$

This "calibration" procedure will need to be repeated several times because:

1. It may not be possible to digitize all the points during one session; therefore, to determine the orientation of the map with respect to the digitizer's axis it is necessary to recalibrate at the beginning of each session. Knowledge of the orientations makes it possible to relate the results of each session to one another;

2. Some digitizers are subject to "drift" (the one at the computing center happens not to be) during a single session, or

the map may shift slightly on the table, thus necessitating recalibration just as though a new session were begun;

3. If the map were too large for the table, it would be necessary to divide it into sections. Calibration points could be chosen within each section and the manual measurement of their co-ordinates would be done with respect to the axis system of the map as a whole. The sections would thereby be correctly positioned with respect to one another. Since the 1"/1000' map of the city of Edmonton did fit on the table, no subdividing was necessary.

The transformations described in this section were performed by the program *DIGICONV[2] provided by Computing Services.

2.4.4 Verifying the Data Base

When the digitizing was completed and the (X,Y) co-

[2] Perry, Mel, Graphitizer, the Digitizer, Univ. of Alta. Computing Services, Edmonton, Alta., Sept. 1972, 35 pp.

ordinates associated with their corresponding Detail Records in the Address/Position, file then the accuracy of the digitizing was verified by the following procedure.

A computer program was written to read the (X,Y) co-ordinates from the data base and to plot the line joining each successive pair of points as appropriate. The map plotted was to the same scale (1"/1000') as the base map. This plotted map and the base map were checked against one another for discrepancies on a light table. These discrepancies were noted and appropriate corrections were made to the Address/Position file. This process of plotting, checking, and altering the Address/Position file was repeated until a satisfactory agreement between the plotted map and the base map was obtained.

The 1971 address ranges were checked against "Henderson's Edmonton Alberta City Directory 1972".[3] Alterations were made to the Address/Position file to reflect discrepancies and to add to information.

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[3] Henderson's Directories, Henderson's Edmonton Alberta City Directory 1972, Henderson's Directories, Ltd, Winnipeg, 1972, pp. 1-327

CHAPTER 3

MANIPULATING THE DATA BASE

3.1 INTRODUCTION

The problem of finding the (X,Y) co-ordinate corresponding to a given address can be accomplished by scanning the Address/Position File (perhaps with the aid of the Index File) until a Master Records containing the ROADNAME of the given address is found. Then the Detail Records for the ROADNAME are scanned to find the address range which contains the given address number. This is done by scanning until the first record whose third field (end address) is equal to or exceeds the given address number. This is the end address of the range, and the begin address of the range is that contained in the first previous record which specifies a begin address. Then an interpolation process is performed using the "X" and "Y" fields of all the records contained within the address range. It should be noted that each (X,Y) co-ordinate pair in the Address/Position File corresponds to the midline of each thoroughfare intersecting at that point. The interpolation procedure calculates the co-ordinates of a point displaced to one side or the other of this midline. In this study it is assumed that all thoroughfares are 66 feet in width, and

hence, displacement is 33 feet from the midline. If the exact street widths are desired, they can be included as an additional field in each Detail Record corresponding to an intersection.

3.1.1 Interpolation Procedure for finding the Position Corresponding to an Address

Let "A" be the given address number, "B" the begin address of the address range, "E" the end address of the address range, and (X_i, Y_i), $i = 0,1,2,\ldots, n$ the (X,Y) co-ordinates from successive records in the range (usually, $n=1$). Let $I_i=1$ if the ith point is an intersection, and 0 otherwise, $i = 0,1,\ldots,n$.

Now let "Si" be the distance between the i and i-1 points in the address range:

$$S_i = \sqrt{(X_{i-1} - X_i)^2 + (Y_{i-1} - Y_i)^2}, \quad i = 1,2,\ldots,n$$

Then let "Dm" be the total distance from the beginning of the address range to the mth point, assuming that each intersection passed is 66 feet in width.

$$D_0 = 0,$$

$$D_m = (S_1 - 66I_1) + (S_2 - 66I_2) + \ldots + (S_m - 66I_m) + 33(I_m - I_0)$$

$$m = 1,\ldots,n$$

Hence, "Dn" is the total distance from the beginning of the address range to the end.

"A" (the address number to be located) must be some fraction, "R", of this total distance "Dn" from the beginning of the range. It is assumed that the address numbers are distributed uniformly along the total distance. Thus

$$R = \frac{A - B}{E - B}$$

If E=B (i.e., there is only one address number in the entire range) "R" is chosen to be one half.

Thus from the total distance "Dn", and the fraction of this distance "R", from the begin point of the range the distance, "L", from the begin point to the given address "A" is:

$$L = R.Dn$$

Once "L" has been determined, it is necessary to determine into which interval between two successive points (bending point, intersection, pseudo-intersection, begin point, end point) "L" extends. That is, find "p" such that:

$$Dp-1 \leq L \leq Dp$$

Then "A" is between (Xp-1, Yp-1) and (Xp,Yp) at a distance of

$$S = (L - Dp-1) + 33Ip-1 \text{ from } (Xp-1,\ Yp-1);\ \text{i.e.,}$$

at

$$Q = \frac{(L - Dp\text{-}1) \pm 33Ip\text{-}1}{Dp}$$

of the distance from (Xp-1,Yp-1) to (Xp,Yp). Thus the co-ordinates of the point, Pmid, on the midline of the 66-foot wide thoroughfare are:

$$Xmid = Xp\text{-}1 + Q(Xp - Xp\text{-}1),$$

$$Ymid = Yp\text{-}1 + Q(Yp - Yp\text{-}1).$$

The point which is actually desired is 33 feet to one side of the midline. Hence, a vector, "Ps", must be added to "Pmid" to arrive at the final point.

Ps must be 33 feet long and orthogonal to:

$$Pg = (Xp - Xp\text{-}1,\ Yp - Yp\text{-}1).$$

Application of distance and orthogonality formulas gives the equations:

1. $(Xs)^2 + (Ys)^2 = 33^2$
2. $Xs(Xp - Xp\text{-}1) + Ys(Yp - Yp\text{-}1) = 0$

After some tedious algebra, these equations yield:

$$Ps = \pm\frac{33}{Sp}(Yp\text{-}1 - Yp,\ Xp - Xp\text{-}1)$$

Inspection shows that the "+" sign corresponds to the left-hand side of the thoroughfare, and the "-" sign to the

right-hand side going from (Xp-1, Yp-1) to (Xp,Yp). It is easy to determine whether "A" is even or odd, and the Master Record specifies on which side of the street the odd numbers are located. Hence, choosing

$$G = \begin{cases} +33 & \text{if (left and A is odd) or (right and A is even),} \\ -33 & \text{otherwise,} \end{cases}$$

the position corresponding to the address "A" is:

$$\left(Xp\text{-}1 + Q(Xp - Xp\text{-}1) + \frac{G(Yp\text{-}1 - Yp)}{Sp},\quad Yp\text{-}1 + Q(Yp - Yp\text{-}1) - \frac{G(Xp\text{-}1 - Xp)}{Sp}\right).$$

See Appendix A for a program to carry out the above procedure.

3.2 PARTITIONING OF MAPS

A city may often be partitioned in a number of different ways; for example, into census districts, wards, postal zones, school districts, land-use zones, police precincts and a host of others. Each such partitioning can be defined by a set of polygons, where each polygon delimits (at least approximately) some subdivision of the city. Each polygon (a closed plane figure of n sides and n vertices) can be specified by the co-ordinates of its vertices.

As part of this study the partitioning of the city of Edmonton into census districts was considered.

Since many of the vertices of the polygons did not correspond to points included in the data base, it was decided to add these points to it. These points have been assigned "thoroughfare names" consisting of the letter "Z" followed by three digits (e.g., Z001, Z022, Z235). Since each of these "thoroughfares" is a single point only, it has been represented by a special form of Master Record, similar to the others except that (X,Y) co-ordinates have been included.

3.2.1 Point-in-Polygon Determination

Given a partitioning, it is often of interest to determine in which of the partitions any given point lies. This problem has been considered in detail by Nordbeck and Rystedt,[1] and their methods will now be described.

In general a polygon can be either "convex" or "concave". A polygon is said to be convex if, for any pair of points inside the polygon (or on its boundaries), no point on the line segment joining that pair lies outside the polygon. If this condition does not obtain, the polygon is concave. Examples of convex polygons are parallelograms and

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[1] Nordbeck, S. and Rystedt, B., Computer Cartography Point in Polygon Programs, Lund Series C, No. 7, C. W. K. Gleerup, Lund, Sweden, 1967, pp. 7-31

triangles, whereas L-shaped and T-shaped figures are concave. (See fig. 4.)

Although many polygons of interest (e.g. some natural regions, census districts) are concave, it will be simpler to consider the case of the convex polygons first.

Consider a triangle "T", which is a special case of a convex polygon. Let (X1,Y1), (X2,Y2), (X3,Y3) be the co-ordinates of the vertices of "T". The area of "T" is given by the formula:

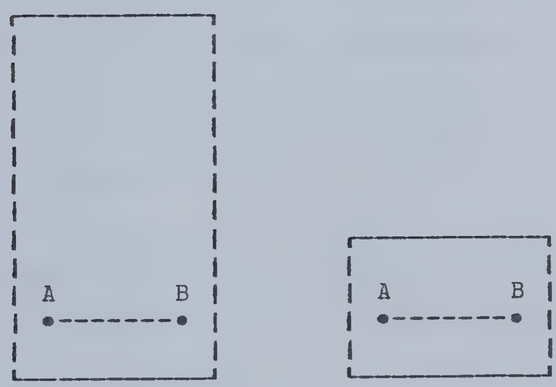
$$A(T) = (X1Y2 + X2Y3 + X3Y1) - (X2Y1 + X3Y2 + X1Y3)$$

If the (Xi,Yi)'s are ordered clockwise around "T" the formula yields a positive result; if they are counter-clockwise, the result is negative. (If the three points are collinear the result is zero.)

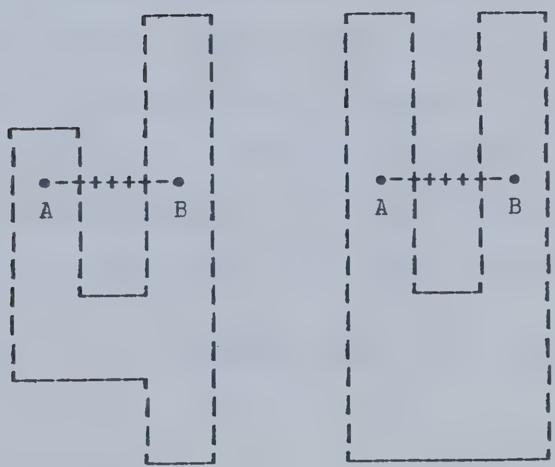
FIGURE 4

EXAMPLES OF CONVEX AND CONCAVE POLYGONS

Convex Polygons



Concave Polygons



Now consider a convex polygon "P" with (n-1) sides whose successive vertices have co-ordinates (Xi,Yi) i=1,..., n-1. To reflect the fact that "P" is a closed figure let (Xn,Yn) = (X1,Y1). The following is the essence of the "orientation theorem", discussed by Nordbeck and Rystedt.[2]

Given any point "Q" with co-ordinates (X,Y), "Q" is contained within "P" if each of the areas:

$$A(T) = (XYi + XiYi{+}1 + YXi{+}1) - (XiY + YiXi{+}1 + XYi{+}1)$$

is of the same sign (i.e., either each A(T)<0, or each A(T)>0). If at least one of the areas is greater than zero, and at least one less than zero, then "Q" lies outside "P". This leaves unresolved the case, in which, one or more of the areas is equal to zero.

Suppose "Q" is collinear with two successive vertices of "P"; then the A(T)=0. If "Q" lies outside of "P" then some of the other areas will be positive and some negative; whereas, if "Q" lies cn "P" then the remaining areas will be of the same sign, except if "Q" is a vertex, in which case, there will be two successive areas equal to zero.

Nordbeck and Rystedt give an ALGOL procedure,

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[2] Ibid., 1967, p. 16 et seq.

NORPCONVEX, which uses the orientation theorem to determine whether a given point lies inside, outside or on a given polygon.[3] A PL/I version of this procedure is given in Appendix B.

Any concave polygon can be partitioned into a number of mutually exclusive convex polygons. The problem of determing whether a point falls within the concave polygon can thereby be reduced to determining whether it is contained in one of those convex polygons.

Suppose now that a map has been suitably partitioned into a number of convex polygons and some point has been given. The problem of determining, in which, of those polygons, if any, the point lies can be solved by considering the individual polygons one after another. However, if there are many polygons, say "C" of them then on the average about "C/2" of the polygons will be tested before the right one is found. If the point lies entirely outside of all the polygons, all "C" of them will have to be tested. Such a search is time consuming and expensive.

In order to render this operation more efficient the following scheme may be employed.

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[3] Ibid., 1967, p. 19

1) When each polygon is initially formed, it is described by the set of co-ordinate pairs of its vertices, and, in addition four other numbers:

   a) lowest X co-ordinate,

   b) highest X co-ordinate,

   c) lowest Y co-ordinate,

   d) highest Y co-ordinate

   of any point contained in the polygon.

2) If the (X,Y) co-ordinates of the point under consideration are outside the above listed bounds of a particular polygon, then that polygon may be rejected immediately.

3.3 VERIFICATION OF ADDRESS FINDING, AND POINT-IN-POIYGON PROCEDURES

This section outlines a method of verifying the address finding and point-in-polygon procedures, and co-incidentally producing a listing, by census district, of some demographic characteristics.

A description of 1971 Census Districts[4] of the city of Edmonton was obtained. It was noted that most of the boundary lines follow railroad rights of way or such natural features as the river, ravines and creeks. These curved boundary lines were, therefore, approximated by sequences of straight lines, thus effectively making each census district into a polygon. Though most of these polygons are convex, some are not. Each concave polygon was subdivided into a number of convex polygons.

Each convex polygon was coded and entered into a file in the form of Master Records and Detail Records. The form of these is shown in fig. 5.

A magnetic-tape file was obtained from Administrative Data Processing, University of Alberta, containing for each staff member: name, address, rank, tenure and gender. In some cases the department or some other address was given rather than the home address. For purposes of this verification such individuals were excluded.

A program was constructed which, using the methods described in section (2.2) and the magnetic-tape file, produced a file containing each address, its corresponding

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[4] Dominion Bureau of Statistics, Description of Census Tracts, Dominion Bureau of Statistics, Geography Section, Census of Canada 1971, Ottawa, 1971, pp. 1-3

(X,Y) co-ordinates and census district (i.e., a record). In addition rank, tenure, status and gender were included for each address. A listing of this file was made and the results were checked by hand.

FIGURE 5

CENSUS DISTRICT FORMATS

Master Records

CODE	MIN X	MAX X	MIN Y	MAX Y

Detail Record

CODE	X	Y

The second and third fields specify the (X,Y) co-ordinates of a vertex of a convex polygon.

In addition rank, tenure, status and gender were included for each address. A listing of this file was made and the results were checked by hand.

Another program was constructed which established a set of counters. For each census district there was a counter for each of assistant, associate and full professor, for tenured staff, and for male staff. These counters were initially set to zero. The file produced by the first program was then read and for each record the appropriate counters for the census district indicated were incremented by one. When all the records had been processed, the program listed the values of the counters as shown in Table I . (See Appendix C for the table and programs.)

CHAPTER 4

APPLICATIONS OF THE DATA BASE

4.1 INTRODUCTION

This chapter discusses one main area of application of the data base and programs, in detail, and sketches a series of others. In addition a number of extensions to the data base to increase the scope of its applicability are suggested.

4.2 RESIDENTIAL PATTERNS

To plan for efficient and orderly development of urban residential, commercial, and industrial areas, and for their corresponding utilities, road networks and other public facilities, planners must have reliable information concerning the composition and mobility patterns of the population concerned. Tracing family histories and the residential moves of individuals throughout their lifetimes involves the processing of masses of data. Equipment for dealing effectively with these large quantities of data has been available for only a relatively short time. In fact, the UNIVAC I, the first generally available computer, was developed specifically to process data for the 1950 United

States census. Even now, when data processing equipment is generally available, much of the data that exists is not in machine-readable form. Increasingly, however, large institutions are maintaining their records on magnetic tapes using computers.

4.2.1 Some Preliminaries

A. The population - Let there be given a specific population from some "system" for for which, during at least one given year, there is a source of personnel data (e.g., age, sex, place of birth, marital status, current address, and education), and, in which, it is possible to determine the residential moves of the individuals either exhaustively, or at intervals over a specified time period.

The term "system" as used here refers to an institution or company with which a number of individuals are associated for some reason, such as, employment, health care, telephone service, gas and water services, and adoption, and where some central agency keeps records on the individuals.

The academic staff at the University of Alberta, for instance, constitutes such a population, because:

1. they are associated with a system - the University of Alberta;

2. there is a magnetic-tape payroll file containing information about each staff member.

It is not suggested that the residential patterns of the academic staff (assistant, associate and full professors) are necessarily representative of the patterns of the population of Edmonton or any other group. Nevertheless, this population has been chosen for use as a standard example in this thesis.

B. The Time Period - Let there be given a time (e.g., 1960-1961 to 1970-1971) over which a study is to be conducted, within the constraints of the information available.

1. Suppose that the only complete information available were for 1970-1971. (In fact at the University of Alberta the tapes are updated continuously, and records are maintained on only the current staff.) Residential addresses can be obtained for previous years by using various directories, resulting in the major limitation that the individuals leaving the system prior to 1970-1971 are missed.

2. Suppose that the only complete

information were available for 1960-1961. This is analogous to the previous situation except that the individuals entering the system after 1960-1961 are missed.

3. Suppose that complete information were available throughout the time period. Individuals entering or leaving during the time period could be included or omitted, as desired.

In the case of the academic staff a type 1 study is possible but might be broadened to type 3 by adding information from "paper" records at the University.

C. The Base Year - Let a base year be chosen, thereby defining a reference population for the period. For studies of types 1 and 2 above the year for which complete information is available would likely be most appropriate, while for type 3 studies any year in the period would be appropriate.

For the purposes of this thesis a copy of the 1970-1971 academic-staff payroll file (with "sensitive" information, such as salaries, removed) was obtained.

D. The Residential Move Interval - Since residential histories are not available on tape each change of residence

must be traced at yearly intervals over the time period (1960-1961 to 1970-1971) using telephone directories.

Problems of using a one-year interval are that:

1. it is assumed that the address listed remains constant during the interval; that is, moves away from and back to a listed address during a year, and multiple moves, are not recorded. It is suspected that an individual is likely to move more frequently at certain critical times; e.g., during the first year of residence in a new city;

2. ordinarily, deaths and departures are not well recorded, and this can be troublesome. In the case of the academic staff this information is available for the base year.

Tracing back in time from the base year to the point of entry, on a yearly basis, using both municipal and University telephone directories, is essentially a screening process, in which the Edmonton addresses would be processed first, then those in the outlying areas.

The computer could be used to list the staff members in alphabetic order by name, and to allocate a line (to be

filled in by hand, from the telephone directories) for each year since appointment. Asterisks could be printed on each line corresponding to a year in which a staff member was on leave of absence. Since leaves of absence are noted on the "Payroll" tape the individuals concerned could be dealt with in the following fashion.

1. If the listing remains the same in three successive telephone directories, bracketing the period of leave, the individual could be considered not to have moved; otherwise,

2. If the listing changes, the individual could be considered to have moved at the time the leave of absence began.

The addresses once traced can be keypunched and merged with the Payroll tape to give an "Address History" file of each individual by year.

Problems anticipated in the use of telephone directories are:

1. females who marry while on staff, as there is no record of their maiden names on the tape file;

2. staff who do not have telephones, or who have unlisted numbers, or who are listed

under someone else's name;

3. difficulties which arise from ambiguous listings; e.g., multiple entries for Jones, R.

The above if not traced might be contacted at the University (the department, building code, and room number are recorded for the base year); otherwise, they would have to be excluded.

When the residential addresses for each member have been traced and stored as a sequential file in computer-readable form, the next step is to render these addresses more useful by relating them to their geographical co-ordinates (X,Y) by using the procedure described in section (2.1).

4.2.2 Static Aspects of Residency

Once the addresses have been related to the (X,Y) co-ordinates it is then possible for each time interval (year) to do any of the following:

1. Using point-in-polygon methods, and appropriate partitionings of the city, to relate the group under study (the academic staff members at the University of Alberta) to census districts, areas

of high, low and medium population density, residential-zoning areas; or any of a multitude of other spatial units. It is possible to take the intersections of each polygon of "A" (e.g., quality of housing) with each polygon of "B" (e.g., population density) to give a larger set of smaller polygons, resulting in a new partitioning "C" of the whole, and to relate each address to this partitioning. For example an address in the partition "high quality" of "A", and in the "low density" of "B" would be in the partition "high quality and low density" of "C". The intersection of any number of partitionings can be computed, and related to each address.

2. Given the locations of regional shopping centers, hospitals, parks and other public facilities, to determine the distance from each residence to the nearest of these facilities and to the University. It might be of interest to determine how these distances and information from the polygons are

related to age, marital status and rank of the academic staff members.

3. Given the (X,Y) co-ordinates of each residence, it is simple to determine the center of population $(\bar{X},\bar{Y})$ of staff members, using the formulas:

$$\bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \quad \text{and}$$

$$\bar{Y} = \frac{\sum_{i=1}^{n} Yi}{n}$$

n = number of addresses

(Xi,Yi) = co-ordinates of the address.

It might be of interest to compare the center of population with the co-ordinates of the University, or with any other point. It might also be of interest to know how the center of population of various subsets of the population may differ. Interesting subsets might be full, associate and assistant professors,

Cross sectional summaries can be produced by counting the number of staff members with a given characteristic

(full, associate, and assistant professor) in each polygon.

4.2.3 Dynamic Aspects of Residency

If the address data spanning the time period is available, two types of mobility patterns may be discerned:

1. Areal Change - without performing any further computations it can be seen whether the areas associated with any particular characteristic (e.g., rank) change with the passage of time and distance from the University.

2. Individual Mobility - with some additional computation it is possible to follow each individual through the ranks and from residence to residence to determine for instance, whether, on the whole, staff members tend to move closer or further from the University as they advance in rank. Any number of correlations between characteristics of staff members and their places of residence can be determined.

4.3 EXTENSIONS TO THE DATA BASE, COMPUTER PROGRAMS AND OTHER APPLICATIONS

In general, geographical information systems can be said to be composed of two parts:

1. the data base, and
2. the set of procedures and methods for manipulating this data base.

Such a system, once constructed, must be extensible in order to accommodate new types of data and new methods of handling data with facility.

4.3.1 Cartography

As was mentioned in section (1.4.5) it is possible to use the data base together with a digital plotter to produce a map on paper. The data base can be updated to reflect changes in the city, and in turn plotted maps of the entire city or portions of it can be quickly, surely, and automatically produced.

The visual form of the map depends upon the programs used to do the plotting. The simplest form of map is a collection of straight-line segments with no labelling. This may be sufficient for some purposes, but it is also possible to label thoroughfares, and to plot the appropriate

curvatures.

A simple extension to the data base would enable maps to be plotted indicating direction of traffic. A further extension would include street widths. These two extensions would also facilitate studies of traffic flow.

Auxiliary files could be created containing records specifying information about such features as hospitals, shopping centers, churches, parks, warehouses and filling stations. Selected information from the auxiliary files could be included on the plotted maps. These files might also be of use in studies of the type discussed in section (3.2.1).

The scope of the data base could be expanded beyond the limits of the city of Edmonton by including such adjoining areas as St. Albert and Sherwood Park.

4.3.2 Simulations

> A simulation ... is an attempt to present reality ... in a convincing manner for purposes of explanation, manipulation, and analysis.... There are two key ingredients of any simulation:
> 1) the systematic selection of a small number of features of reality for explanation, manipulation and analysis;
> 2) the collapsing and/or expanding of the time scale.
> A simulation model is a simulation which is governed by some predetermined and consistent rules for handling and manipulating events and information as they are

introduced into the simulation.[1]

Though the topic of simulation, in general, is beyond the scope of this study, it may, nevertheless, be remarked that the data base, as possibly extended, provides a necessary framework for traffic-flow and other simulations.

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[1] Kibel, Barry M., Simulation of the Urban Environment, Assoc. of Amer. Geog., Technical Paper Series No. 5, Washington, D. C., 1972, p. 13

CHAPTER 5

CONCLUSION

The first objective of this project was to construct a data base representing a map of the city of Edmonton. This has been accomplished using records like those in fig. 3. The accuracy of the data base was verified by using it to plot a street map of the city. A small portion of this map is given in Appendix D.

A further objective was to construct a utility program, which, given a city address, calculates the location at which that address occurs in the city. A second utility program was constructed which, when given a location and a partitioning of the city into polygonal areas, computes which of the areas, if any, contains the location. These programs are given in Appendices A and B.

The use of the data base and these utility programs is demonstrated in Appendix C, which calculates and prints the distribution of the academic staff of the University of Alberta by census districts as shown in Table I.

The design of the data base is flexible enough to permit expansion of the territory covered, and to allow for inclusion of additional kinds of information such as the

designation of street widths and direction of traffic flow.

Since updating is straightforward using standard computer programs, the data base can be kept up-to-date with changes in the city, and any errors which may be discovered can be easily corrected.

Construction of this data base plus the utility programs constitutes only a small step in the direction of automating urban analysis. It is believed that, if location-specific data is collected systematically, in machine-readable form, then much profitable use can be made of the data base described in this thesis.

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APPENDIX A

INTERPOLATION PROCEDURE FOR FINDING THE POSITION CORRESPONDING TO AN ADDRESS

```
SEARCH:
  PROCEDURE(ROAD, A, X, Y);
  DCL ROAD CHAR(24), (A, X, Y) FIXED BIN(30);

  DCL ABLR STATIC CHAR(1),
      (S(10), D(0:10)) FLOAT,
      (XX, YY, I)(0:10) STATIC FIXED BIN(30),
      (B, E, N) STATIC FIXED BIN(30),
      (K, K1, P, P1, MODA) FIXED BIN(30),
      (G, L, R, Q, XMID, YMID) FLOAT,
      GETSER ENTRY RETURNS(BIT(1));

  ON ENDFILE(ADPOS)  GOTO FINIS;

  IF ROAD = MAINROAD THEN
  DO; IF B <= A & A <= E THEN GOTO INTERPOLATE; END;
  ELSE
  DO; IF ROAD < MAINROAD THEN
    DO; X, Y = 1000001;
      PUT LIST('ADDRESS', A, ROAD, 'OUT OF ORDER')SKIP;
      RETURN;
    END;
    ELSE
    DO;
      DO WHILE (ROAD > MAINROAD);
         READ FILE(ADPOS) INTO (LINE);
         IF SUBSTR(LINE, 5, 3) = '000' THEN
           MAINROAD = SUBSTR(LINE, 9, LENGTH(LINE) - 8);
      END;
      ABLR = SUBSTR(LINE, 8, 1);
      IF GETSER THEN RETURN;
    END;
  END; /* MAIN ROAD HAS BEEN FOUND */
```

APPENDIX A
(continued)

```
LOOP:
  E = SUBSTR(LINE, 28, 5);
  DO WHILE (E = 0 | E > A + 100);
    IF GETSER THEN RETURN;
    E = SUBSTR(LINE, 28, 5);
  END;

  XX(0) = SUBSTR(LINE,  9, 6);
  YY(0) = SUBSTR(LINE, 15, 6);
  IF SUBSTR(LINE, 8, 1) = '#'
    THEN I(0) = 0;
    ELSE I(0) = 1;
  IF GETSER THEN RETURN;
  N = 0;
  B = SUBSTR(LINE, 22, 5);

  DO WHILE (B = 0);
    N = N + 1;
    XX(N) = SUBSTR(LINE,  9, 6);
    YY(N) = SUBSTR(LINE, 15, 6);
    IF SUBSTR(LINE, 8, 1) = '#'
      THEN I(N) = 0;
      ELSE I(N) = 1;
    IF GETSER THEN RETURN;
    B = SUBSTR(LINE, 22, 5);
  END;
```

APPENDIX A
(continued)

```
INTERPOLATE:
  D(0) = 0;
  DO K = 1 TO N;
    K1 = K - 1;
    S(K) = SQRT((XX(K1) - XX(K)) ** 2 +
                (YY(K1) - YY(K)) ** 2);
    D(K) = D(K1) + S(K) - HW * (I(K) + I(K1));
  END;
  IF E = B
    THEN R = 0.5;
    ELSE R = FLOAT(E - A) / FLOAT(E - B);
  L = R * D(N);
  IF L <= 0.0 THEN L = 0.0;
  ELSE DO WHILE (L > D(N)); L = L * .99999; END;
  P = 1;
  DO WHILE (L > D(P));
    P = P + 1;
  END;
  P1 = P - 1;
  IF D(P) = 0.0
    THEN Q = 0.0;
    ELSE Q = ((L - D(P1)) + HW * I(P1)) / D(P);
  XMID = XX(P1) + Q * (XX(P) - XX(P1));
  YMID = YY(P1) + Q * (YY(P) - YY(P1));

  IF ABLR = ' ' THEN G = 0.0;
    ELSE IF ABLR = 'A' THEN G =  HW;
    ELSE IF ABLR = 'B' THEN G = -HW;
    ELSE
    DO; MODA = MOD(A, 2);
      IF (ABLR = 'L' & MODA = 1) |
         (ABLR = 'R' & MODA = 0)
        THEN G =  HW;
        ELSE G = -HW;
    END;
  IF S(P) = 0.0
    THEN G = 0.0;
    ELSE G = G / S(P);

  X = FIXED(XX(P1) + Q * (XX(P) - XX(P1)) -
                     G * (YY(P) - YY(P1)), 30);
  Y = FIXED(YY(P1) + Q * (YY(P) - YY(P1)) +
                     G * (XX(P) - XX(P1)), 30);
  RETURN;
```

APPENDIX A
(continued)

```
  GETSER: PROCEDURE RETURNS(BIT(1));
  DCL LSER CHAR(7);
    LSER = SUBSTR(LINE, 1, 7);
    DO WHILE (SUBSTR(LINE, 1, 7) = LSER);
      READ FILE(ADPOS) INTO (LINE);
    END;
    IF SUBSTR(LINE, 5, 3) = '000' THEN
    DO; PUT LIST('ADDRESS', A, ROAD, 'NOT FOUND')SKIP;
      MAINROAD = SUBSTR(LINE, 9, LENGTH(LINE) - 8);
      PUT LIST('ADVANCED TO   ', MAINROAD)SKIP;
      ABLR = SUBSTR(LINE, 8, 1);
      READ FILE(ADPOS) INTO (LINE);
      X, Y = 1000002;
      B = 1000000; E = -1;
      RETURN('1'B);
    END;
    ELSE RETURN('0'B);
  END GETSER;

FINIS: X, Y = 1000000;
    PUT LIST('END OF ADDRESS/POSN FILE REACHED')SKIP;
    PUT LIST('LOOKING FOR ', A, ROAD)SKIP;
END SEARCH;
```

APPENDIX B

POINT-IN-POLYGON DETERMINATION

```
SELECT:
    PROCEDURE(X, Y) RETURNS(FIXED BIN(30));
       DCL (X, Y) FIXED BIN(30);
     /* IT IS ASSUMED THAT PX(*), PY(*), CODE(*),
     M(*), N(*), XMIN(*), XMAX(*), YMIN(*), YMAX(*),
     AND NP  ARE GLOBALLY DECLARED. */

    /* THIS PROCEDURE SELECTS, ON THE BASIS OF THEIR
       MINIMUM AND MAXIMUM X AND Y COORDINATES,
       A FEW OF THE POLYGONS FOR DETAILED STUDY BY
       PROCEDURE  PRON  , WHICH IS CALLED WHENEVER
       THE POINT PRESENTED IS WITHIN THE BOUNDS OF
       SOME POLYGON. IF PRON FAILS TO FIND THE POINT
       IN THE POLYGON, THEN  SELECT  SEARCHES FOR ANY
       FURTHER CANDIDATES.  */

      DCL (I, J) FIXED BIN(30);
      DO I = 1 TO NP;
        IF X < XMIN(I) | X > XMAX(I) THEN GOTO NEWI;
        IF Y < YMIN(I) | Y > YMAX(I) THEN GOTO NEWI;
        J = PRON(X, Y, M(I), N(I), PX, PY);
        IF J >= 0 THEN RETURN (CODE(I));
 NEWI:END;
        RETURN (-1);
        /* IN CASE THE POINT IS IN NONE OF THE POLYGONS */
      END SELECT;
```

APPENDIX B
(continued)

```
PRON:
 PROCEDURE(X, Y, M, N, PX, PY) RETURNS(FIXED BIN(30));
      DCL (X, Y, M, N) FIXED BIN(30),
          (PX(*), PY(*)) FIXED BIN(30);

        /*PRON IS A GENERALIZATION OF NORPCONVEX.
        (PX(I), PY(I)),  I=M, M+1, M+N-1 ARE THE
        CO-ORDINATES OF SUCCESSIVE VERTICES
        OF A POLYGON - THEY MUST BE IN ORDER,
        BUT THIS ORDER MAY BE EITHER CLOCKWISE
        OR COUNTERCLOCKWISE. PRON DETERMINES WHETHER
        THE POINT (X,Y) IS INSIDE (+1), OUTSIDE (-1),
        OR ON THE BOUNDARY (0) OF THE POLYGON */

        DCL (A, I, MN1, S, XI, YI, YI1) FIXED BIN(30);

        MN1 = M + N - 1;
        DO I = M TO MN1;
           XI = PX(I); YI = PY(I);
           IF I = M THEN
           DO; XI1 = PX(MN1); /* NORP REQUIRES EXTRA */
               YI1 = PY(MN1); /* ELEMENTS FOR THIS */
               S = 0; /* NEUTRAL VALUE FOR SIGN */
           END;
           ELSE
           DO; XI1 = PX(I-1);
               YI1 = PY(I-1);
           END;
           A = X   * (YI  - YI1) +
               XI  * (YI1 - Y  ) +
               XI1 * (Y   - YI );
           IF A = 0 THEN   /* ABS(A) < EPSILON? */
           DO;
              IF SIGN(X - XI) = SIGN(X - XI1)
              THEN RETURN (-1); /* OUTSIDE */
              ELSE RETURN (0); /* ON BOUNDARY*/
           END;
           IF (A < 0 & S > 0) | (A > 0 & S < 0)
             THEN RETURN (-1);
             ELSE S = SIGN(A); /* TOO EARLY TO TELL */
        END;
        /*THE POINT IS INSIDE IFF  WE GET THIS FAR */
        RETURN (1);
    END PRON;
```

APPENDIX C

UTILITY PROGRAMS

```
MAINPR:
     PROCEDURE OPTIONS(MAIN);
     DCL (NP, NV, ND, A, X, Y, DIS, RNK,
         TN, ST, GN, AG, I) FIXED BIN(30),
         LINE CHAR(150) VARYING,
         (ROAD, MAINROAD) CHAR(24),
         HW FIXED BIN(30) INIT(33); /* HALF ROAD WIDTH */
    /* NP IS NO. OF CONVEX POLYGONS,
       NV IS NO. OF VERTICES MAKING UP THOSE POLYGONS, AND
       ND IS NO. OF "DISTRICTS" MADE UP BY THE POLYGONS */

    READ FILE(POLY) INTO (LINE);
    GET STRING(LINE) LIST(NP, NV, ND);

    BEGIN;
      DCL RANK(ND, 3) FIXED BIN(30),
          (TEN, GEN, STA)(ND, 2) FIXED BIN(30),
          (TOT, AGE)(ND) FIXED BIN(30),
          (SELECT, PRON) RETURNS(FIXED BIN(30)),
          (XMIN, XMAX, YMIN, YMAX, M, N, CODE)
                                 (NP)FIXED BIN(30),
          (PX, PY)(NV) FIXED BIN(30),
          AVG FLOAT;

      CALL READPOLY;  /* INPUT POLYGON DEFINITIONS */

      DO I = 1 TO ND;
        RANK(I,1), RANK(I,2), RANK(I,3),
         TEN(I,1),  TEN(I,2),
         GEN(I,1),  GEN(I,2),
         STA(I,1),  STA(I,2),
           TOT(I),    AGE(I) = 0;
      END;

      LINE = '                                                ';
      MAINROAD = '                        ';
      ON ENDFILE(ACSTAF) GOTO SUMMARY;
```

APPENDIX C
(continued)

```
 NEXT:
   GET FILE(ACSTAF) EDIT (A, ROAD, RNK, TN, ST, GN, AG)
     (F(5), X(1), A(24), F(3), F(5), F(5), F(3), F(4))
     SKIP;

   CALL SEARCH(ROAD, A, X, Y);
   IF X > 999999 THEN
   DO; IF X = 1000000 THEN GOTO SUMMARY;
                      ELSE GOTO NEXT;
   END;

   DIS = SELECT(X, Y);
   IF DIS < 0 THEN GOTO NEXT;
   DIS = FLOOR((DIS + 5)/100);
   IF RNK > 0 THEN RANK(DIS,RNK) = RANK(DIS,RNK) + 1;
   IF  TN > 0 THEN  TEN(DIS, TN) =  TEN(DIS, TN) + 1;
   IF ST = 1
     THEN SSTT = 1;
     ELSE SSTT = 2;
   STA(DIS,SSTT) = STA(DIS, SSTT) + 1;
   AGE(DIS) = AGE(DIS) + AG;
   IF GN = 1
     THEN GEN(DIS,1) = GEN(DIS,1) + 1;
     ELSE IF GN > 1 THEN GEN(DIS,2) = GEN(DIS,2) + 1;
   TOT(DIS) = TOT(DIS) + 1;
   GOTO NEXT;

SUMMARY:
   PUT LIST(
'DIST    RANK        TENURE    GENDER    MARITAL   TO-  AVG'
                                        )SKIP; PUT LIST(
'RICT                                     STATUS   TAL  AGE'
                                        )SKIP; PUT LIST(
'    ASST ASOC FULL  YES   NO MALE  FEM  MAR SING')SKIP;
   DO I = 1 TO ND;
     X = TOT(I);
     IF X = 0
       THEN AVG = 0.0;
       ELSE AVG = 71E0 - FLOAT(AGE(I)) / FLOAT(X);
     PUT EDIT( I, RANK(I,1), RANK(I,2), RANK(I,3),
           TEN(I,1), TEN(I,2), GEN(I,1), GEN(I,2),
           STA(I,1), STA(I,2), TOT(I), AVG)
            (F(3),(10)F(5),F(5,1))SKIP;
   END; /* END OF PROGRAM PROPER */
```

APPENDIX C
(continued)

```
READPOLY:
    PROCEDURE;
        /* READ IN POLYGON DEFINITIONS */
           DCL (PI, VI, ACODE, LCODE, LM) FIXED BIN(30);
         /* PX(*), PY(*), CODE(*), M(*), N(*),
            XMIN(*), XMAX(*), YMIN(*), YMAX(*),
            AND LINE  ARE GLOBALLY DECLARED */
        ON ENDFILE(POLY) GOTO FINISH;
        LCODE = -1;
        PI = 1;
        VI = 1;
   LOOP:READ FILE(POLY) INTO (LINE);
        ACODE = SUBSTR(LINE, 1, 5);
        IF ACODE  = LCODE THEN
        DO; /*MASTER RECORD */
           LCODE = ACODE;
           CODE(PI) = ACODE;
           GET STRING(LINE) EDIT (XMIN(PI),
           XMAX(PI), YMIN(PI), YMAX(PI))
           (X(6),F(6),X(1),F(6),X(1),F(6),X(1),F(6));
           IF PI > 1 THEN N(PI-1) = VI - LM;
           LM, M(PI) = VI;
           PI = PI + 1;
        END; ELSE
        DO; /*DETAIL RECORD */
           GET STRING(LINE) EDIT (PX(VI), PY(VI))
                      (X(6), F(6), X(1), F(6));
           VI = VI + 1;
        END;
        GOTO LOOP;
     FINISH:   /* PI - 1 IS NUMBER OF POLYGONS */
        N(PI-1) = VI - LM;
     END READPOLY;

 /* HERE INCLUDE THE DECLARATIONS FOR PROCEDURES
    SEARCH, GETSER, SELECT AND PRON, GIVEN IN
    APPENDICES A AND B.  */

 END;  /* END OF BEGIN BLOCK */
END;
```

TABLE I

RESIDENTIAL DISTRIBUTION OF STAFF

BY 1971 CENSUS DISTRICTS

DIST RICT	RANK			TENURE		GENDER		MARITAL STATUS		TO- TAL	AVG AGE
	ASST	ASOC	FULL	YES	NO	MALE	FEM	MAR	SING		
1	2	1	0	0	3	3	0	2	1	3	36.3
2	19	15	1	7	13	35	0	31	4	35	38.0
3	11	26	18	5	43	54	1	49	6	55	41.1
4	12	35	15	6	48	59	3	54	8	62	41.5
5	5	4	2	4	4	10	1	10	1	11	36.3
6	0	0	0	0	0	0	0	0	0	0	0.0
7	1	2	1	0	3	4	0	3	1	4	50.5
8	7	6	2	1	8	15	0	10	5	15	43.2
9	2	10	6	2	13	16	2	14	4	18	45.2
10	26	47	67	15	106	124	16	117	23	140	46.7
11	16	16	20	6	38	44	8	41	11	52	43.9
12	9	3	2	7	6	13	1	12	2	14	39.8
13	8	4	1	4	8	12	1	9	4	13	39.2
14	0	0	0	0	0	0	0	0	0	0	0.0
15	1	1	1	1	2	3	0	3	0	3	44.7
16	1	2	0	1	1	3	0	2	1	3	35.3
17	1	0	0	1	0	1	0	1	0	1	28.0
18	0	0	0	0	0	0	0	0	0	0	0.0
19	2	0	1	1	1	3	0	2	1	3	37.3
20	2	4	2	2	4	6	2	6	2	8	43.1
21	10	5	1	4	7	13	3	11	5	16	38.8
22	28	15	9	14	19	43	9	30	22	52	39.4
23	40	56	57	37	91	127	25	107	46	153	46.7
24	6	2	1	2	2	9	0	7	2	9	40.1
25	0	0	0	0	0	0	0	0	0	0	0.0
26	5	2	3	2	4	10	0	9	1	10	40.9
27	3	4	6	5	8	11	2	7	6	13	46.1
28	2	0	1	1	1	2	1	3	0	3	33.0
29	5	5	5	3	8	12	3	10	5	15	47.5
30	7	2	1	4	4	7	3	6	4	10	44.4
31	1	1	0	0	0	2	0	1	1	2	40.0
32	27	8	9	29	6	39	4	34	10	44	46.9
33	1	1	0	1	1	2	0	1	1	2	32.5
34	2	1	0	3	0	3	0	3	0	3	53.0
35	1	3	0	0	3	4	0	3	1	4	46.3
36	0	3	1	0	3	4	0	3	1	4	44.3
37	1	1	1	1	1	3	0	2	1	3	47.3

TABLE I
(continued)

DIST RICT	RANK ASST	RANK ASOC	RANK FULL	TENURE YES	TENURE NO	GENDER MALE	GENDER FEM	MARITAL STATUS MAR	MARITAL STATUS SING	TO- TAL	AVG AGE
38	0	1	0	0	1	1	0	1	0	1	43.0
39	0	1	0	0	1	1	0	1	0	1	54.0
40	1	1	2	0	2	4	0	2	2	4	48.5
41	1	0	1	0	1	1	1	2	0	2	40.0
42	1	0	0	1	0	1	0	1	0	1	31.0
43	1	0	2	1	2	2	1	2	1	3	48.3
44	1	0	0	0	1	1	0	0	1	1	32.0
45	0	0	0	0	0	0	0	0	0	0	0.0
46	3	0	0	2	0	3	0	1	2	3	34.3
47	0	0	0	0	0	0	0	0	0	0	0.0
48	2	2	1	2	3	4	1	3	2	5	42.0
49	2	3	0	0	3	3	2	3	2	5	46.2
50	0	0	0	0	0	0	0	0	0	0	0.0
51	0	0	0	0	0	0	0	0	0	0	0.0
52	0	1	0	0	1	0	1	0	1	1	55.0
53	1	3	0	1	3	4	0	4	0	4	47.3
54	0	0	0	0	0	0	0	0	0	0	0.0
55	1	0	1	0	2	2	0	2	0	2	34.5
56	0	0	0	0	0	0	0	0	0	0	0.0
57	0	1	0	0	1	1	0	0	1	1	51.0
58	0	0	0	0	0	0	0	0	0	0	0.0
59	0	0	0	0	0	0	0	0	0	0	0.0
60	1	0	0	1	0	1	0	0	1	1	39.0
61	0	0	0	0	0	0	0	0	0	0	0.0
62	0	0	0	0	0	0	0	0	0	0	0.0
63	1	0	0	1	0	1	0	1	0	1	32.0
64	0	0	1	0	1	1	0	1	0	1	41.0
65	1	1	0	0	2	2	0	2	0	2	34.5
66	0	1	0	0	1	1	0	1	0	1	49.0
67	0	0	0	0	0	0	0	0	0	0	0.0
68	1	0	0	1	0	1	0	1	0	1	28.0
69	0	0	0	0	0	0	0	0	0	0	0.0
70	0	0	0	0	0	0	0	0	0	0	0.0
71	0	0	0	0	0	0	0	0	0	0	0.0
72	1	0	0	0	0	1	0	1	0	1	38.0
73	0	0	0	0	0	0	0	0	0	0	0.0
74	0	0	0	0	0	0	0	0	0	0	0.0
75	0	0	0	0	0	0	0	0	0	0	0.0
76	0	0	0	0	0	0	0	0	0	0	0.0
77	0	0	0	0	0	0	0	0	0	0	0.0

APPENDIX D

PLOT OF A SECTION OF THE CITY OF EDMONTON